JPL Autonomy Program Overview

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JPL The research described in this talk was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Autonomy Challenges of Deep Space Missions

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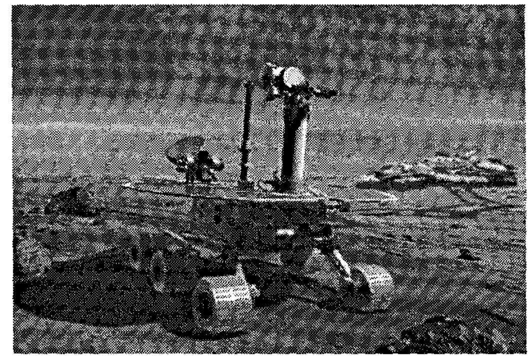
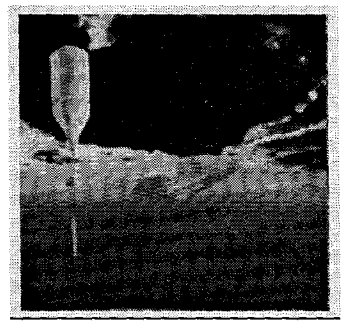
Autonomy Drivers:

- Dynamic, unpredictable environment
- Unknown/poorly known environment
- Infrequent, low-data rate communications
- Uncertain navigation
- Operations costs

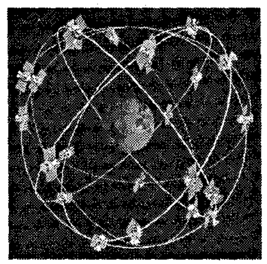


Martian rover



Titan Aerobot

Spacecraft Constellations & Sensor Webs



Europa Hydrobot

Needed Autonomy Capabilities:

- Goal-driven, fail operational behavior
- Robust execution under uncertainty
- Identify & exploit science opportunities
- Constellation management & operations

Intelligent Systems Program

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- NASA/Code-R funded program to develop autonomy technology for future space missions

- Four Thrust Areas
  - ⇨ **Automated Reasoning**: planning, execution, fault diagnosis, …
  - ⇨ **Intelligent Data Understanding**: data mining, pattern recognition, . . .
  - – **Human Centered Computing**: human factors, VR, …
  - – **Revolutionary Computing:** e.g., quantum & bio-inspired

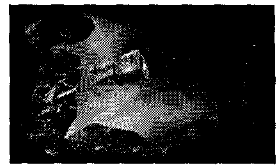
- Competitive proposals via NASA Research Agreements (NRA)
  - – *joint NASA/industry & NASA/university proposals encouraged*

Autonomy Components & Goals

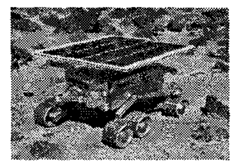
Autonomy Thrust

- Onboard Planning & Execution
- Intelligent Science Data Analysis
- Distributed Autonomy
- Health Monitoring & Diagnosis

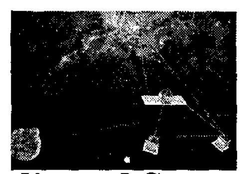
Near Term



Opportunistic Science

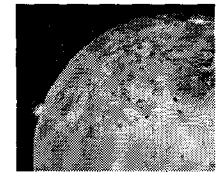


Self-managing Explorers

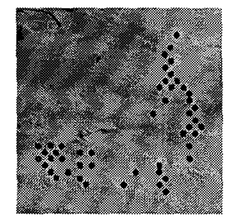


Coordinated Spacecraft Fleets

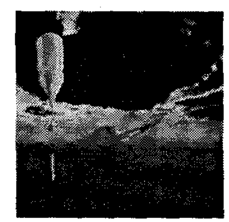
Long Term



Vigilant, Sustained Presence



Robot Colonies



Exploration of Uncertain Environments

Planning & Execution

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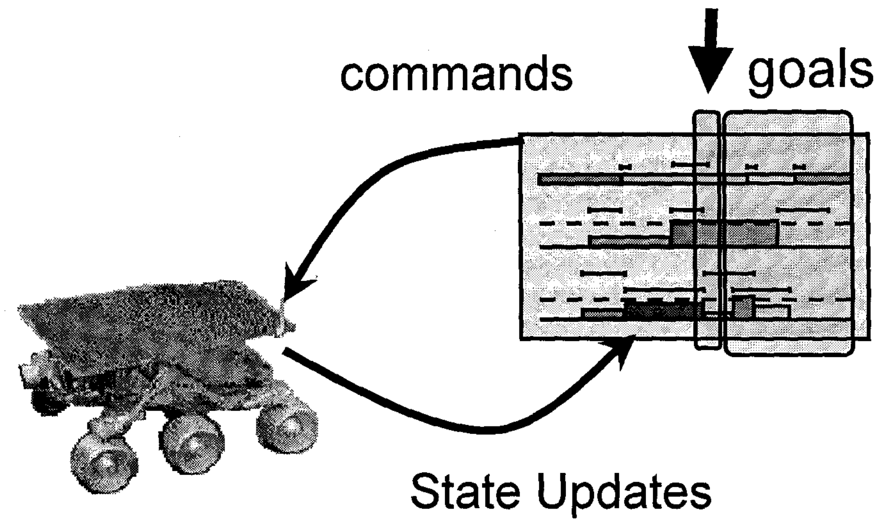
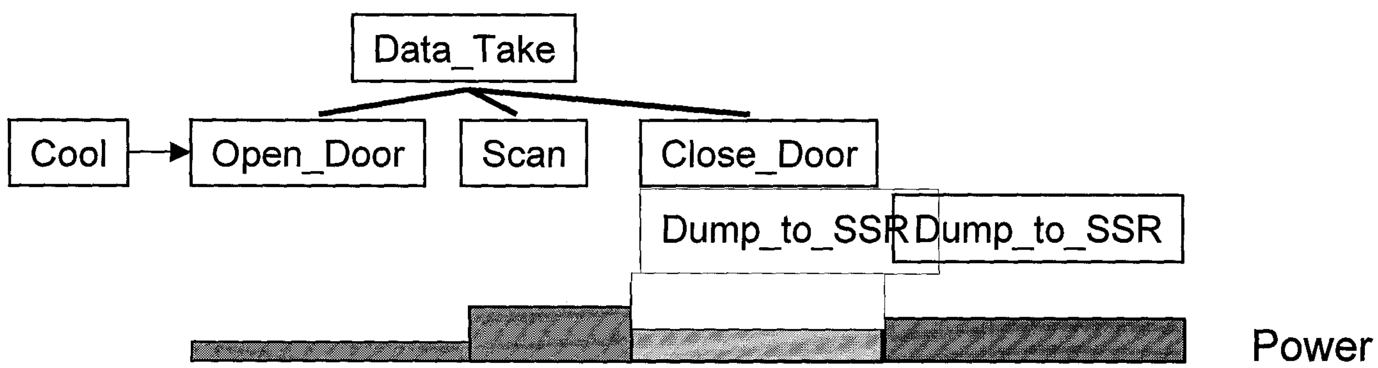
Planning & Scheduling



Technology: **ASPEN/CASPER**

- Automatically generate plan of action that achieves goals while obeying resource & operations constraints.

- Continuously revises plan in response to events (~10s)

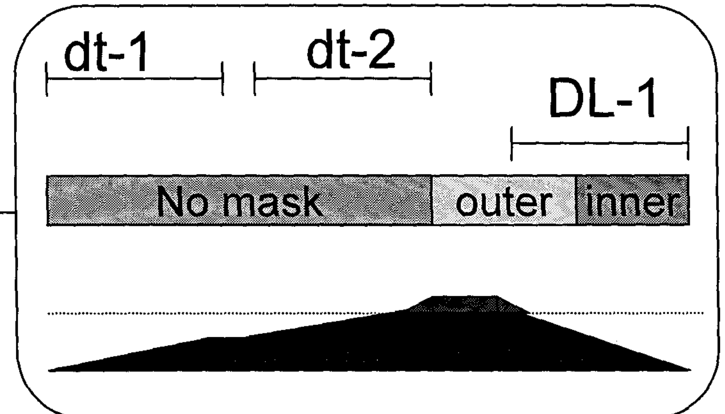


ASPEN Components

Domain Model
encodes constraints

Activity **Data_Take**
uses *duration* sec of tape;
Activity **Downlink**
must occur during innner mask;
frees *duration* sec of tape;
Resource **Tape**
capacity = 15 min;

Plan

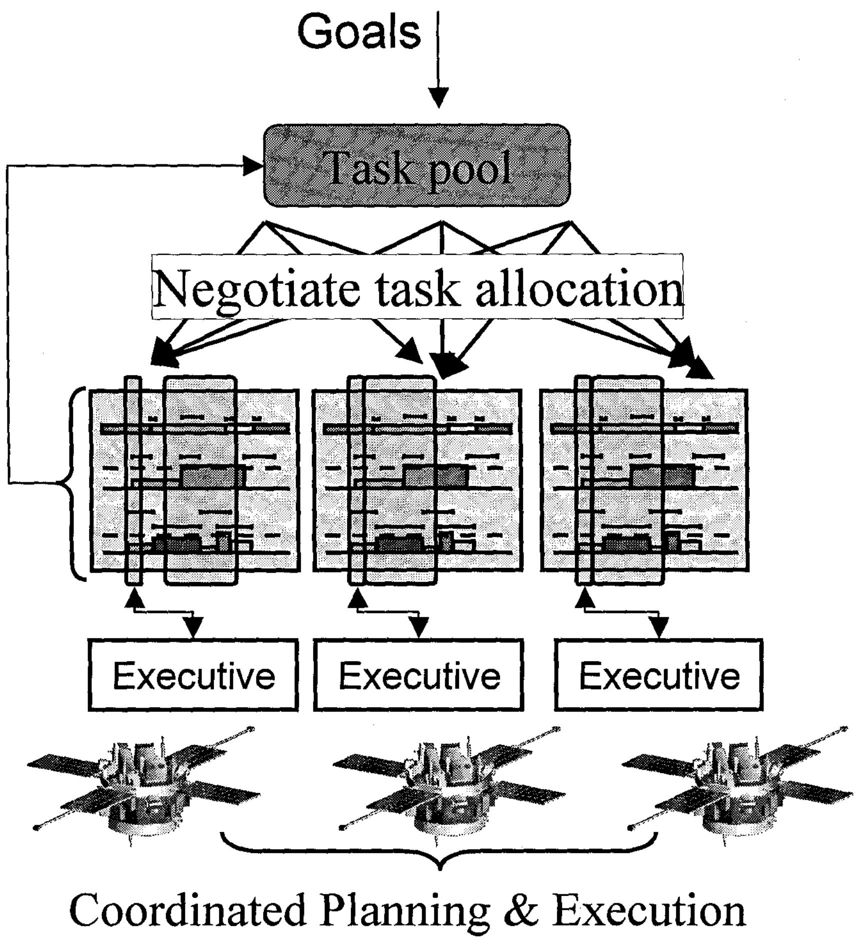


Constraint tracker
detect violations

- dl-1 not during inner
- tape-used > 15m

Planning Engine
Hierarchical decomposition
Insert activities to achieve goals
Detect & resolve conflicts

Team Planning for Constellations



Technology

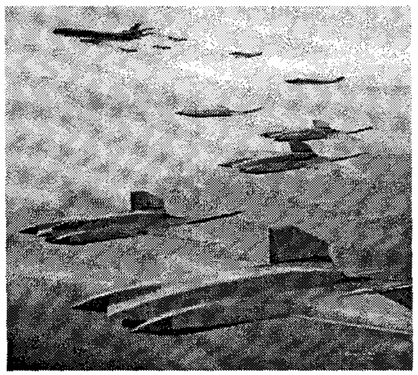
- Planners on each spacecraft negotiate to best allocate goals & resolve conflicts among respective plans.
- Planners replan / reallocate as needed during execution to coordinate activities.

Approaches:

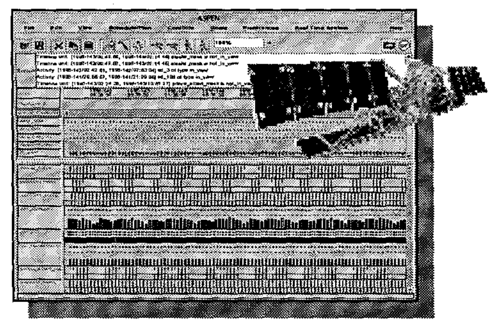
- Loose (goal distribution)
  - Centralized 'distribution' planner
  - Contract network
- Tight coordination

Scalable, coordinated commanding and execution will enable future constellation and fleet missions.

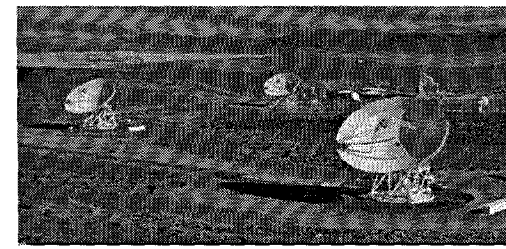
ASPEN & CASPER Deployments



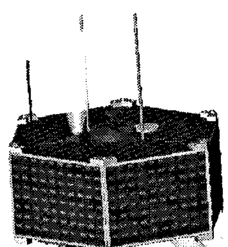
Unpiloted aerial vehicles



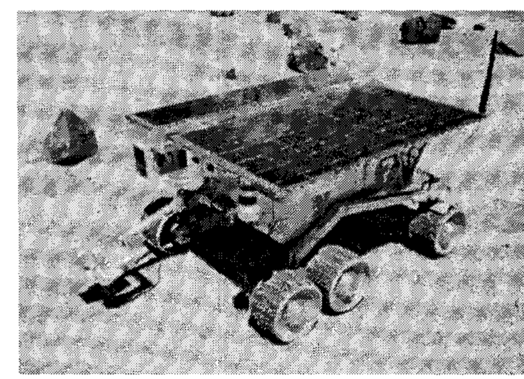
Automated Mission Planning for MAMM
(reduced planning effort 10x wrt similar manually planned mission)



Ground station automation (CLEaR)



3 Corner Sat (3CS)
Launch: 2002 (with CSGC)



Autonomous rover control (Rocky7, Rocky8)

Some Active Planning Research Topics . . .

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- Plan optimization
- High-speed planning algorithms/heuristics
- Integrating special-purpose solvers
- Adaptive problem solving
- Unified planning & execution
- Team planning & execution

Intelligent Data Analysis

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Intelligent Science Data Analysis

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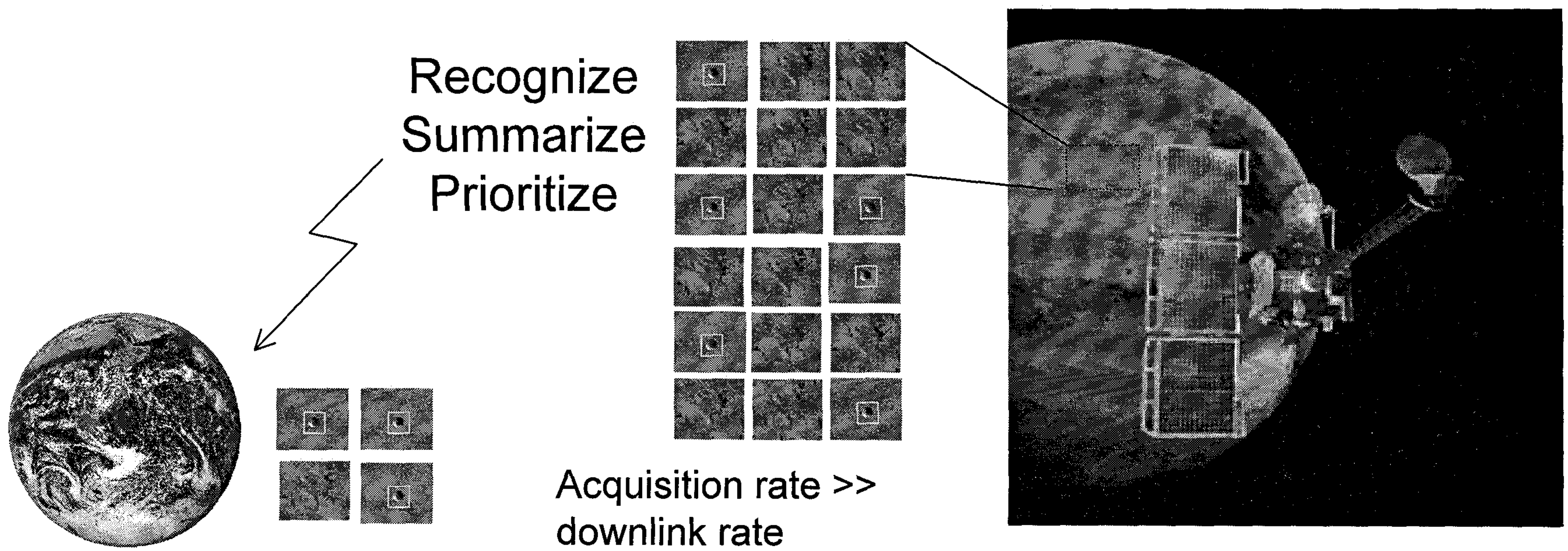
- Detect science events: Craters, solar features, surface motion, statistical outliers, ...
- Respond to events: reduce bandwidth & acquire short-lived events
  - Discard & reacquire 'bad' data
  - Evaluate data & send 'best' data first
  - Process raw data & send only results
  - Schedule follow-up observations of breaking science events
  - Scan continuously for infrequent, hard-to-predict events



ASC Mission Scenario

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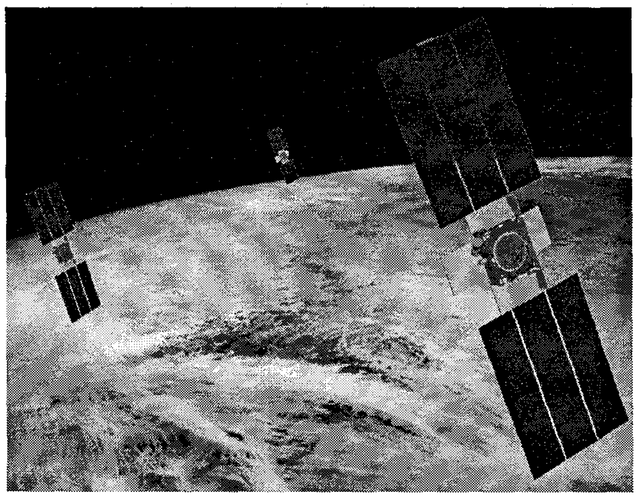
Cluster Management:
Constellation
Reconfiguration

Target Imaging:
Autonomous Spacecraft
Reconfiguration

Onboard Science
Processing and Event
Detection

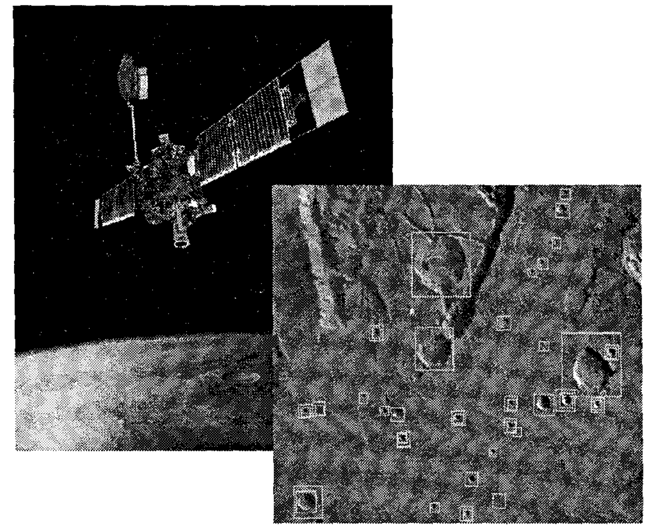
Onboard Replanning



Onboard Science Analysis and Knowledge Discovery

Technology: DiamondEye

Automatically detect craters and other scientifically interesting features in image data.



Craters detected in Viking data

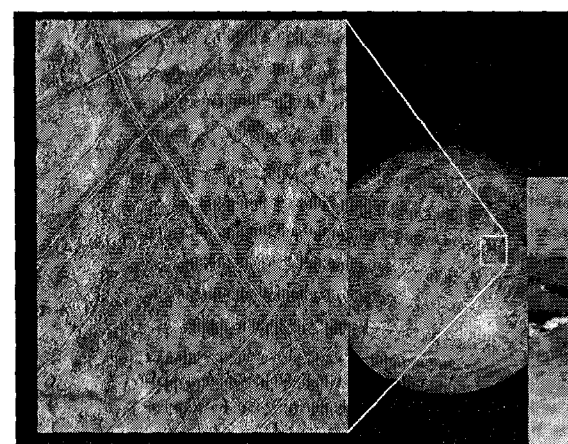
Innovations

Learns scale- and rotation-invariant pattern recognizers from a few examples

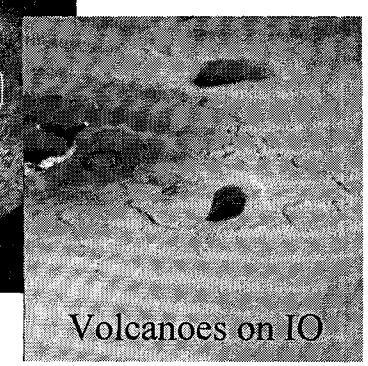
Discovers ‘anomalous’ features--these could be big science discoveries.

Applications

- Machine-assisted discovery of phenomena in vast datasets
- Opportunistic Science
- Data Prioritization & Summarization



Europan ice motion

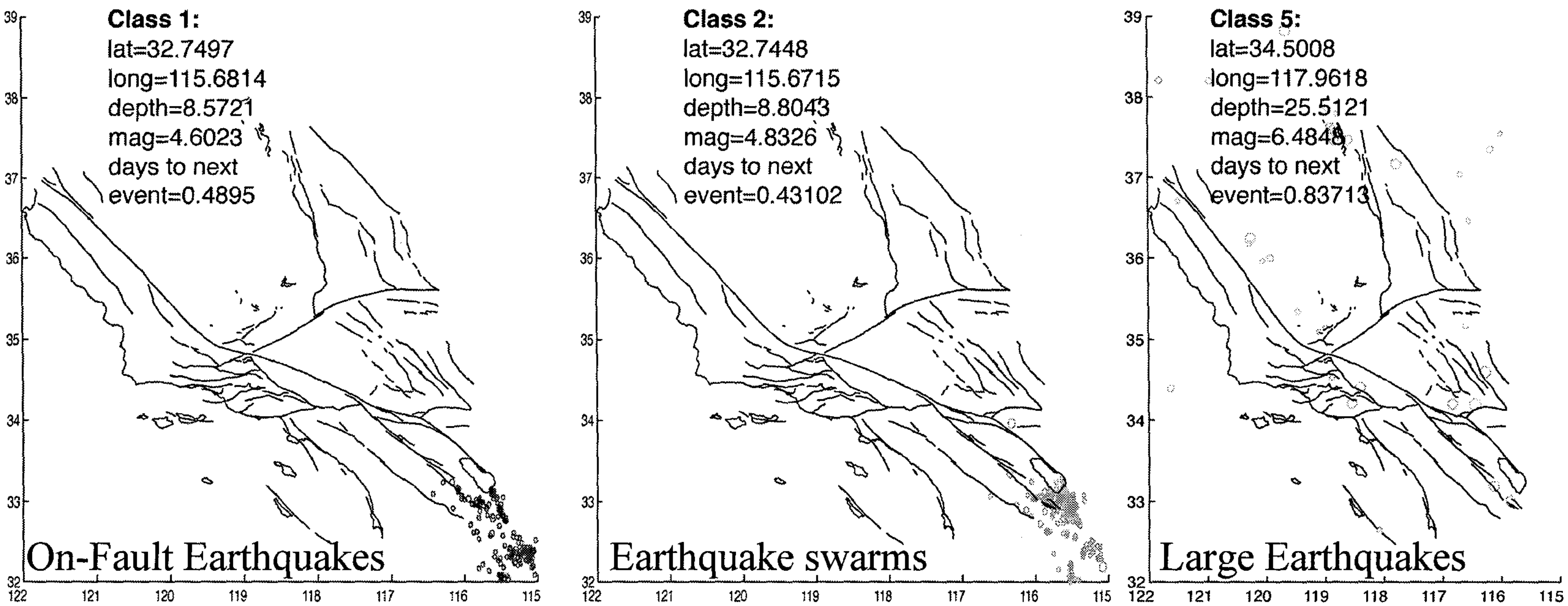


Volcanoes on IO

Automated Analysis of Sensor Webs

Dr. Andrea Donnellan

Hidden Markov modeling of seismic time series reveals interesting patterns in seismic data. Earthquakes are automatically classified into classes of large earthquakes, earthquakes occurring on fault structures, and classes of earthquake swarms.

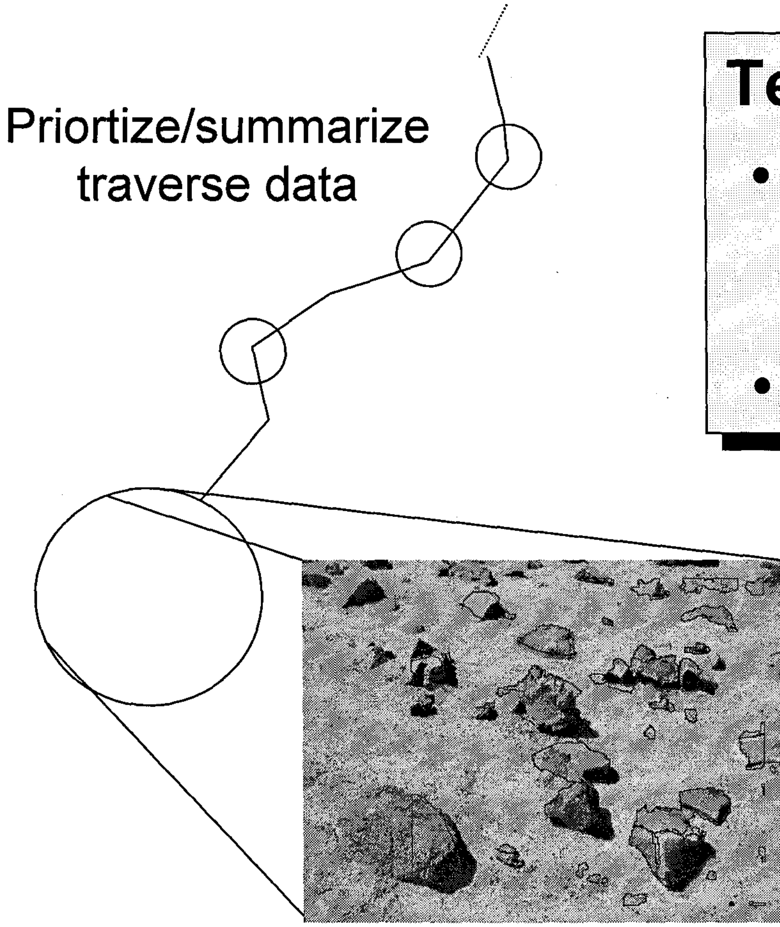


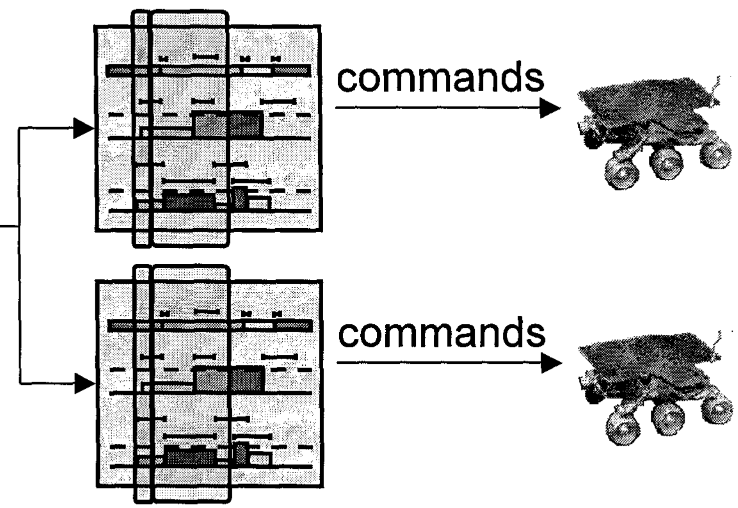
Other interesting results show that earthquake classes occur forshallow, moderate, and deep earthquakes. The likelihood of one of these classes transitioning into itself is low, but the likelihood of transitioning into one of the other depth classifications is high. This suggests that stress is relieved at the depth at which the earthquake occurred and is transferred up or down in the crust.

Rover Science Autonomy

Technologies:

- geological data understanding
  - science feature recognition
  - geological process models
- onboard planning & execution





- Detect & prioritize science targets
- Distribute goals among multiple rovers
- Acquire science data, recover from failures

Some Active Data Understanding Topics . . .

- Data mining time-series engineering data *(when was the last time the star tracker acted like this?)*
- *Image pattern recognition*
- *Data mining & feature recognition for distributed sensor webs*

Health Monitoring & Diagnosis

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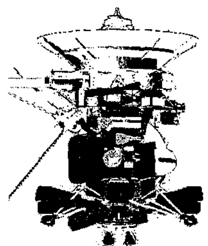
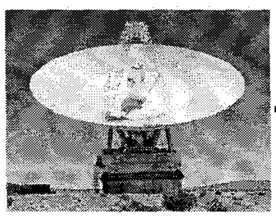
Health Monitoring & Diagnosis: BEAM

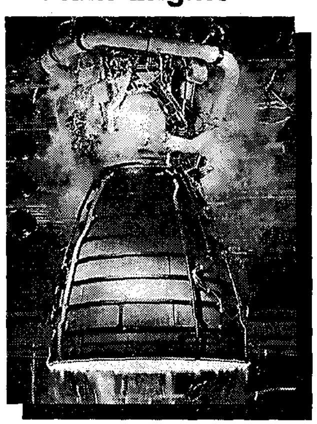


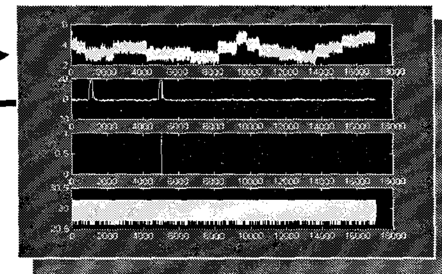
Cassini

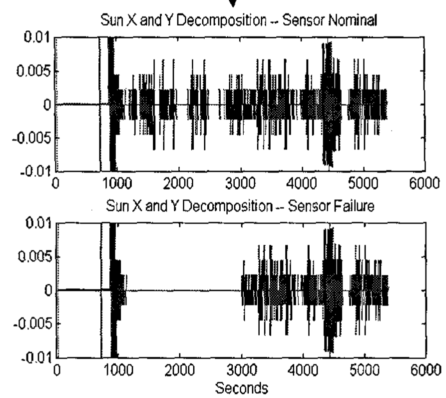
DSN



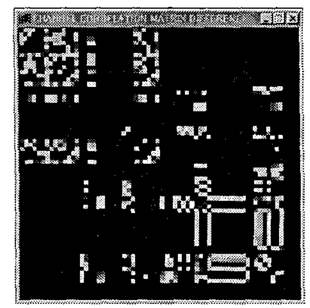
Space shuttle Main Engine





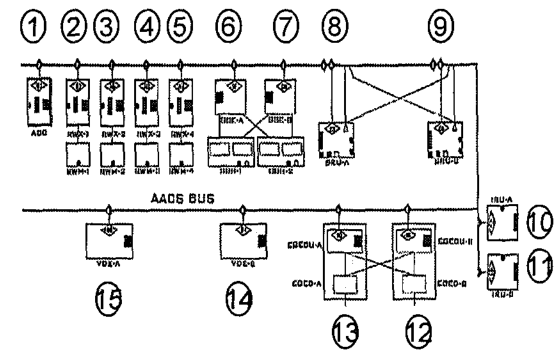


Trending



ζ -plot

Cross-signal Fault Detection



Fault Isolation

ADVANCES

- **Low false alarm rate and high precision detection**
- **Can detect and isolate unmodeled faults**
- **High-precision Trending**
- **Cross-signal methods provide very high accuracy mode**

BEAM Applications

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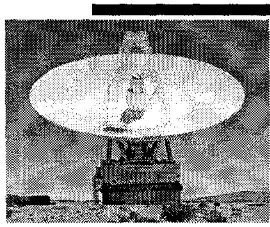
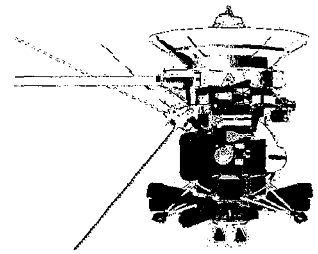


- DSN DSS-14 70m Antenna Hydrostatic Bearing

– Outperformed human analysts by detecting
  - Detected onset of failure faster than the operators
  - Isolated anomalies that expert operators failed to correctly identify

– Demonstrated predictive detection capability: 2-week lead time in predicting onset of failure



- CASSINI AACS / JPL MSAS

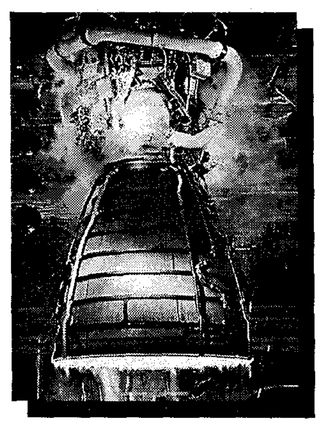
– BEAM able to detect errors beyond the AACS FSW design envelope and provide quantitative degradation assessment

– Ongoing work to integrate BEAM tools with MSAS (Cassini, DS1, SIRTF)

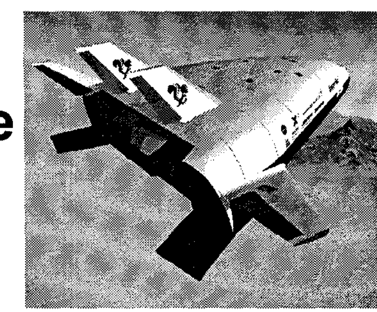
Space Shuttle Main Engine

- Successfully distinguished and identified all faults
- Exceeded existing fault protection

Ongoing work with MSFC
  - Develop engineering tools to monitor engine tests and track degradation
  - Scale up for in-flight experiments



X-33 Aerospike and LOX Tank



Conducted shadow experiment on Aerospike Power Pack
- Perfect fault detection and identification
- Exceeded operator false-alarm performance

Summary

- Future NASA missions needs are strong autonomy driver
  - Autonomy technologies are being developed to meet those needs
  - Many challenges remain: good collaboration opportunities

- JPL autonomy technologies are also applicable to non-NASA domains
  - UAV, submersibles, DoD/NRO applications

- For more info:
  - http://cs.jpl.nasa.gov
  - http://www-aig.jpl.nasa.gov